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## TWO-DIMENSIONAL WIND-TUNNEL INVESTIGATION OF SIX AIRFOIL SECTIONS FOR THE WING OF THE VEGA XP2V-1 AIRPLANE

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NACA



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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

# TWO-DIMENSIONAL WIND-TUNNEL INVESTIGATION OF SIX AIRFOIL SECTIONS FOR THE WING OF THE VEGA XP2V-1 AIRPLANE

By Felicien F. Fullmer, Jr.

## SUMMARY

An investigation was conducted in the Langley two-dimensional low-turbulence pressure tunnel of six airfoil sections for the wing of the Vega XP2V-1 airplane. Two of these sections, the NACA $65_2$-515 (modified) a = 1.0 and the Lockheed D-12A airfoils were tested as possible tip sections and the remaining four, the

$$\text{NACA } 65_{(318)}\text{-}419 \begin{Bmatrix} a = 1.0, & c_{l_i} = 0.5 \\ a = 0.8, & c_{l_i} = -0.5 \\ a = 0.5, & c_{l_i} = 0.4 \end{Bmatrix}$$

, the NACA 2418, the Lockheed D-20B, and the Vega airfoil were tested as possible root sections for the wing of the subject airplane. The Vega airfoil was also tested with a 30-percent chord Fowler type flap. The general aerodynamic characteristics were determined for each of these airfoils in a smooth condition and with standard leading-edge roughness. The tests of the airfoil-flap model were made to determine the effect of a flap gap seal and Reynolds number on the lift characteristics for intermediate flap deflections and to determine the best gap dimension for a flap deflection of 32°.

The results indicate that the aerodynamic characteristics of no one airfoil in the smooth condition were superior in all respects to those obtained for any of the other airfoils as shown by the following table of characteristics obtained at a test Reynolds number of 9,000,000:

| Airfoil | $\frac{dc_l}{d\alpha_o}$ | $c_{l_{max}}$ | $c_{d_{min}}$ | Range of lift for low drag | $c_{m_{a.c.}}$ |
|---|---|---|---|---|---|
| NACA $65_2$-515 (modified) a = 1.0 | 0.108 | 1.655 | 0.0043 | 0.250 to 0.740 | -0.086 |
| Lockheed D-12A | .109 | 1.555 | .0047 | .500 to .840 | -.059 |
| NACA $65_{(318)}$-419 $\left\{\begin{array}{l} a = 1.0,\ c_{l_i} = 0.5 \\ a = 0.8,\ c_{l_i} = -0.5 \\ a = 0.5,\ c_{l_i} = 0.4 \end{array}\right\}$ | .112 | 1.460 | .0046 | -.160 to .650 | -.047 |
| Lockheed D-20B | .103 | 1.330 | .0048 | --------------- | -.060 |
| NACA 2418 | .103 | 1.475 | .0068 | --------------- | -.044 |
| Vega (modified) 2419 | .098 | 1.440 | .0053 | --------------- | -.051 |

The addition of leading-edge roughness produced marked separation effects and the resultant increase in drag coefficient was of sufficient magnitude that the airfoils, with the exception of the NACA 2418 and the Lockheed D-12A, were considered as unconservative sections. The maximum lift coefficient, for flap deflections greater than 8°, was appreciably increased when the flap gap seal was removed and the greatest maximum lift coefficient for a flap deflection of 32° was obtained with a gap dimension equal to 2.7 percent of the airfoil chord.

## INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, an investigation was carried out in the Langley two-dimensional low-turbulence pressure tunnel to determine the aerodynamic characteristics of six plain airfoil sections for the wing of the Vega XP2V-1 airplane. One of these sections, a Vega airfoil, was later modified to include tests with a 30-percent chord Fowler type flap.

The investigation of the plain airfoils consisted of tests to determine the lift, drag, and pitching-moment characteristics of the airfoil sections and to obtain some data concerning the sensitivity of these sections to leading-edge roughness. The investigation of the airfoil-flap model included tests to determine the effect of a flap gap seal and Reynolds number on the lift characteristics of the model with the flap partially deflected and also to determine the best gap setting for the maximum flap deflection of 32°.

## LIST OF SYMBOLS

| | |
|---|---|
| $c_d$ | section drag coefficient $(d/qc)$ |
| $c_{d_{min}}$ | minimum section drag coefficient |
| $c_{l_i}$ | section design lift coefficient |
| $c_l$ | section lift coefficient $(l/qc)$ |
| $c_{l_{max}}$ | maximum section lift coefficient |
| $\Delta c_{l_{max}}$ | maximum section lift coefficient increment |
| $c_{m_{c/4}}$ | section pitching-moment coefficient about airfoil quarter-chord point $\left(\frac{m_{c/4}}{qc^2}\right)$ |
| $c_{m_{a.c.}}$ | section pitching-moment coefficient about the aerodynamic center $\left(\frac{m_{a.c.}}{qc^2}\right)$ |
| $\frac{dc_l}{d\alpha_o}$ | slope of the lift curve per degree of angle of attack |
| R | Reynolds number |
| $\alpha_o$ | section angle of attack |
| $q_o$ | free-stream dynamic pressure $\left(\frac{\rho V^2}{2}\right)$ |
| c | airfoil chord |

x distance along chord measured from the leading edge; horizontal position of the aerodynamic center

y distance above or below chord line, positive when above chord line; vertical position of the aerodynamic center

d drag per unit span

$l$ lift per unit span

m moment per unit span

ρ air density

## MODELS AND TESTS

The airfoil models tested were of wood construction and had a chord of 24 inches. The 30-percent-chord Fowler flap which was tested with the Vega airfoil section was constructed of duralumin and was furnished by the Vega Aircraft Company. A sketch of the various airfoil profiles are shown in figure 1 and the ordinates are presented in tables I to VI. The major differences in the various airfoil sections is shown by the plot of the profiles presented in figure 1. The NACA $65_2$-515 (modified) a = 1.0 airfoil was obtained by combining a modified NACA $65_2$-015 basic thickness distribution and a mean line of the type a = 1.0 having a design lift coefficient of 0.5. The modification of the basic thickness distribution consisted of removing the cusp and substituting a straight-line fairing from the 60-percent station to the trailing edge. The Vega airfoil was a modified NACA 2419 airfoil section. Essentially the modification of the NACA 2419 airfoil consisted of changing the position of the maximum thickness from 0.30 to 0.38 of the chord and using a smaller leading-edge radius to arrive at a section which would resemble a low-drag airfoil. A comparison of the profiles of this modified section and a conventional NACA 2419 airfoil is shown in figure 2. A sketch showing the general arrangement of the Vega airfoil-flap model, flap profile, flap ordinates, and gap dimensions is presented in figure 3.

The general aerodynamic characteristics of the plain airfoils were determined for Reynolds numbers of

3,000,000, 6,000,000, and 9,000,000 with corresponding values of the Mach number of 0.108, 0.144, and 0.158. The lift and drag characteristics at a Reynolds number of 6,000,000 were also determined with standard roughness applied to the leading edge of each of the airfoil sections. The standard roughness applied to these models was the same as that described in reference 1. The lift characteristics of the Vega airfoil-flap model were, with one exception, obtained at a Reynolds number of 9,000,000. To determine what scale effect would be obtained on this model for flap deflections of 0°, 4°, 8°, 16°, and 24°, additional lift characteristics were obtained for one gap configuration for a Reynolds number of 6,000,000.

Corrections for the wind-tunnel-wall effects were made by the following equations where the primed quantities represent the aerodynamic coefficients measured in the tunnel:

$$\alpha_o = 1.015\alpha_o'$$

$$c_l = (0.985 - 0.34K)c_l'$$

$$c_d = (1 - 0.034K)c_d'$$

$$c_{m_{c/4}} = (1 - 0.034K)c_{m_{c/4}}'$$

| Airfoil | K |
|---|---|
| NACA $65_2$-515 (modified) a = 1.0 | 0.284 |
| Lockheed D-12A | .220 |
| NACA $65_{(318)}$-419 $\left\{\begin{array}{l} a = 1.0,\ c_{l_i} = 0.5 \\ a = 0.8,\ c_{l_i} = -0.5 \\ a = 0.5,\ c_{l_i} = 0.4 \end{array}\right\}$ | .370 |
| Lockheed D-20B | .428 |
| NACA 2418 | .376 |
| Vega | .380 |

A correction has also been applied to the data presented in this report for the increased blocking effect at angles of attack in the neighborhood of maximum lift. This correction for the increased blocking effect reduces the maximum lift coefficient measured in the tunnel by approximately 1.5 percent. A full explanation of these corrections and a discussion of the accuracy of routine airfoil tests are presented in the appendix of reference 1.

## RESULTS AND DISCUSSION

The section lift, drag, and pitching-moment characteristics of the tip sections are presented in figures 4 and 5; similar characteristics for each of the four root sections are presented in figures 6 through 9. The results obtained from tests to determine the scale effect on the Vega-airfoil-flap model with the flap gap sealed are presented in figure 10. The lift characteristics for this model with the flap gap open are presented in figure 11. The results obtained from the tests to determine the best gap setting for the airfoil flap model with the flap at a maximum deflection of 32° are presented in figure 12. The variation of maximum lift with flap deflection for all test configurations of the flap model is presented in figure 13.

Plain airfoils.- The NACA $65_2$-515 (modified) a = 1.0 airfoil section (fig. 4) was tested as a possible tip section for the wing of the Vega XP2V-1 airplane. The aerodynamic characteristics of this section, as would be expected, approximate those for an NACA $65_2$-415 airfoil (reference 1) since both sections have the same thickness and somewhat similar pressure distributions. A comparison, at a Reynolds number of 9,000,000, between the NACA $65_2$-515 (modified) a = 1.0 airfoil and the NACA $65_2$-415 airfoil of reference 1 shows that the maximum lift coefficients for both sections were approximately the same; the minimum drag and the pitching-moment coefficients of the NACA $65_2$-515 (modified) a = 1.0 airfoil were, however, somewhat greater than those obtained for the NACA $65_2$-415 airfoil (reference 1). The greater pitching-moment and higher drag coefficients for the NACA $65_2$-515 (modified) a = 1.0 airfoil may be attributed to the higher camber and the modified basic thickness distribution of this airfoil section. It can be seen in figure 4 that the application of roughness to the leading edge of the NACA $65_2$-515 (modified) a = 1.0 airfoil reduced the lift-curve slope and caused some loss in lift coefficient at all positive angles of attack. The figure also shows that the addition of leading-edge roughness reduced the maximum lift coefficient from $c_l = 1.565$ to $c_l = 1.225$ and increased the minmum drag coefficient from $c_d = 0.0045$ to $c_d = 0.0104$. These values are approximately the same as would be obtained from a rough conventional airfoil of equal thickness and would be considered as normal effects of roughness; the very rapid increase in drag coefficient for lift coefficients greater than $c_l = 0.6$, however, indicates the onset of marked separation effects. If it is assumed that the airplane would have a normal wing and power loading and that in the cruise condition the wing would operate at a lift coefficient of approximately 0.6, the NACA $65_2$-515 (modified) a = 1.0 airfoil would in all probability be an unconservative section for this airplane wing because for lifts greater than $c_l = 0.6$ the drag coefficients with leading-edge roughness were excessively high. A more complete definition of an unconservative airfoil and a detailed discussion of the method used to determine whether or not a section is unconservative can be found in reference 1.

The tests results of the Lockheed D-12A airfoil (fig. 5) shows that the aerodynamic characteristics of this section compares favorably with those obtained for the NACA $64_1$-412 airfoil of reference 1. This section was chosen for purposes of comparison because it is equal in thickness and has approximately the same design lift coefficient as the Lockheed D-12A airfoil. A comparison between the Lockheed D-12A and the NACA $64_1$-412 airfoils (reference 1) shows that, for all Reynolds numbers tested, the maximum lift coefficient is considerably lower for the Lockheed D-12A airfoil. The data also shows that the minimum value of the drag coefficient and the range of lift coefficients for low drag are approximately the same for both airfoils; the pitching-moment coefficients, however, are somewhat smaller for the Lockheed D-12A airfoil. The addition of roughness to the leading edge of the Lockheed D-12A airfoil reduced the maximum lift coefficient from $c_l = 1.490$ to $c_l = 1.250$ and increased the minimum drag coefficients from $c_d = 0.0046$ to $c_d = 0.0097$. These changes in lift and drag coefficients are similar to those obtained under the same test conditions, for the NACA $64_1$-412 airfoil and the conventional airfoils of reference 1. Furthermore the increase in drag coefficient with increasing positive lift indicates that only normal progressive separation effects are evident and the airfoil can be considered as a conservative airfoil section.

The NACA $65_{(318)}\text{-}419 \left\{\begin{array}{l} a = 1.0,\ c_{l_1} = 0.5 \\ a = 0.8,\ c_{l_1} = -0.5 \\ a = 0.5,\ c_{l_1} = 0.4 \end{array}\right\}$ airfoil was one of several airfoils investigated for use as a possible root section for the wing of the XP2V-1 airplane. A comparison of the aerodynamic characteristics of this airfoil with those obtained from tests of the other airfoils (see figs. 7, 8, and 9) shows that, in general, the maximum lift coefficients of this section were higher at all Reynolds numbers than those obtained with either the Lockheed D-20B or the Vega airfoil. The maximum lift coefficients for this section were, however, lower than those obtainable with the NACA 2418 airfoil section. The minimum drag coefficient of this NACA 65-series airfoil was lower at all Reynolds numbers than those obtained with any of the other three root sections. The drag coefficients for this airfoil at low negative lift coefficients are about the same as those for any of the other three airfoils; the drag coefficients for lift coefficients greater than $c_l = 0.8$, however, are excessively high. These excessively high drag coefficients and the abrupt changes in the lift-curve slope at these lift coefficients may be attributed to a partial breakdown of flow over the airfoil upper surface. The addition of roughness caused a loss in the lift coefficients, a greatly reduced lift-curve slope, and a very rapid increase in drag coefficient near maximum lift. This indicates that the addition of leading-edge roughness caused a further breakdown of the flow over the airfoil and showed that this NACA 65-series section was unconserative.

The maximum lift coefficients for the Lockheed D-20B airfoil for Reynolds numbers of 6,000,000 and 9,000,000 were considerably lower than those obtained for the NACA 65 series, the NACA 2418 airfoil, and the Vega airfoil sections. The drag coefficients obtained for this section for lift coefficients greater than $c_l = 0.2$ are, in general, lower than those obtainable with any of the other root sections. The minimum drag coefficients for this section were approximately the same as those for the NACA 65-series airfoil and were considerably lower than those obtained with either the Vega or the NACA 2418 airfoil sections. The pitching-moment coefficients about the aerodynamic center obtained for this airfoil were slightly higher than the $c_{m_{a.c.}}$ values obtained for the NACA 65-series, NACA 2418, or the Vega airfoil sections. The Lockheed D-20B airfoil was very sensitive to leading-edge roughness as shown by the large change in the lift-curve slope, the very low maximum lift coefficient, and the excessively high drag coefficients at lift coefficients greater than 0.6. These characteristics are typical of airfoils showing marked separation effects caused by roughness. The Lockheed D-20B airfoil therefore appears to be definitely unconservative.

The maximum lift coefficients of the NACA 2418 airfoil (fig. 8) are not exceptionally high when compared with similar data for other conventional sections of equal thickness; they are, however, higher for all Reynolds numbers tested than those for either the NACA 65 series, the Lockheed D-20B, or the Vega airfoil sections. A comparison of the minimum drag coefficients of this section with those for the other root airfoils reported herein shows that highest minimum drag coefficients were obtained with the NACA 2418 airfoil section. The pitching-moment coefficients of this section are, in general, smaller than those obtained with any of the other root sections. The roughness data presented in figure 8 shows that there is no loss in lift coefficient at low positive angles of attack and no appreciable change in lift-curve slope except near maximum lift. The roughness data also shows that the drag coefficient increases somewhat more rapidly with lift coefficient than for the smooth airfoil but the variation remains normal, increasing progressively with increasing lift coefficient. Because only the usual progressive separation effects are evident the airfoil is a conservative airfoil section.

The maximum lift coefficients of the Vega airfoil (see fig. 9) were higher for all Reynolds numbers tested than those obtained with the Lockheed D-20B airfoil. The drag coefficients obtained with the Vega airfoil for lift coefficients greater than $c_l = 0.2$ were, in general, higher than those obtained with any of the other root sections. The minimum drag coefficients for the Vega airfoil section were lower than those obtained with the NACA 2418 airfoil but were somewhat higher than those obtained with the NACA 65-series and the Lockheed D-20B airfoils. The pitching-moment coefficients for the Vega section were, in general, about the same or slightly greater than those obtained for the NACA 65-series and the NACA 2418 airfoils and were slightly smaller than those obtained with the Lockheed D-20B airfoil. The data presented in figure 9 shows that the addition of roughness to the leading edge of this airfoil resulted in a reduction in the slope of the lift curve and caused a rather rapid increase in the drag coefficient as the lift approached its maximum value. This shows that the model was very sensitive to leading-edge roughness and in all probability the excessively high drag coefficients for lift coefficients greater than $c_l = 0.6$ indicates that this would be an unconservative airfoil section.

A summary of the aerodynamic characteristics obtained for each of these airfoils at a test Reynolds number of approximately 9,000,000 is presented in table VII.

Vega airfoil-flap model.- The scale effect data in figure 10, was obtained from tests with the flap gap sealed and showed that a change in the Reynolds number from 6,000,000 to 9,000,000 resulted in an average increment of 0.07 in the maximum lift coefficient for the airfoil-flap model for flap deflections of 0°, 4°, 8°, 16°, and 24°.

The effect on maximum lift coefficients of removing the flap gap seal is shown in figure 13. The results indicate that no change in the maximum lift coefficients was obtained for flap deflections from 0° to 8°; the results, however, show that for deflections of 16° and 24° an appreciable increase in the maximum lift coefficient was obtained with the flap gap open. In terms of percent increase in lift this represents a 3.7-percent increase at 16° deflection and a 9.3-percent increase at a deflection of 24°. The greater lift at these flap deflections, with the gap open, probably results from better flow characteristics over the upper surface of the flap. In order to determine the best gap dimension for the Fowler flap at a deflection of 32°, tests were made with flap gap dimensions of 1.7, 2.2, and 2.7 percent of the airfoil chord. A gap of 2.2 percent of the airfoil chord was the normal gap for this flap deflection and figure 12 shows that a maximum lift coefficient of 3.15 was obtained for this gap setting. A decrease in the gap dimension to 1.7 percent of the chord caused a slight change in the lift-curve slope and reduced the maximum lift coefficient by approximately 0.6 percent. An increase in the gap dimensions from 2.2 to 2.7 percent of the chord resulted in an increase of 4.1 percent in the maximum lift coefficient even though the lift coefficients over the greater part of the angle-of-attack range (see fig. 12) were somewhat reduced.

The results show that, with a gap dimension of 2.7 percent of the airfoil chord and with the flap deflected 32°, a maximum lift coefficient of 3.28 and a maximum lift coefficient increment of 1.84 was obtained for this model at a Reynolds number of 9,000,000. This maximum lift coefficient and maximum lift coefficient increment compares quite favorably with the maximum lift coefficient of 3.15 and the maximum lift coefficient increment of 1.65 which was obtained (under similar test conditions) for a 15-percent-thick Boeing $W_{53}$ airfoil equipped with a 30-percent chord Fowler flap.

## CONCLUSIONS

The results of the aerodynamic investigation of the six plain airfoils and the airfoil-flap model in the Langley two-dimensional low-turbulence pressure tunnel indicate that:

1. The aerodynamic characteristics of no one airfoil were superior in all respects to those obtained for any of the other airfoils as shown by the following table of characteristics obtained at a test Reynolds number of 9,000,000:

| Airfoil | $\frac{dc_l}{d\alpha_o}$ | $c_{l_{max}}$ | $c_{d_{min}}$ | Range of lift for low drag | $c_{m_{a.c.}}$ |
|---|---|---|---|---|---|
| NACA $65_2$-515 (modified) a = 1.0 | 0.108 | 1.655 | 0.0043 | 0.250 to 0.740 | -0.086 |
| Lockheed D-12A | .109 | 1.555 | .0047 | .500 to .840 | -.059 |
| NACA $65_{(318)}$-419 {a = 1.0, $c_{l_i}$ = 0.5; a = 0.8, $c_{l_i}$ = -0.5; a = 0.5, $c_{l_i}$ = 0.4} | .112 | 1.460 | .0046 | -.160 to .650 | -.047 |
| Lockheed D-20B | .103 | 1.330 | .0048 | -------------- | -.060 |
| NACA 2418 | .103 | 1.475 | .0068 | -------------- | -.044 |
| Vega (modified) 2419 | .098 | 1.440 | .0053 | -------------- | -.051 |

2. The addition of roughness to the leading edge of the plain airfoils produced marked separation effects and the resultant increase in drag coefficient was of sufficient magnitude that the airfoils, with the exception of the NACA 2418 and Lockheed D-12A, were considered to be unconservative sections.

3. The maximum lift coefficient, for flap deflections greater than 8° could be appreciably increased by removing the flap gap seal.

4. The greatest maximum lift coefficient ($c_l = 3.28$) for a flap deflection of 32° was obtained with a flap gap dimension equal to 2.7 percent of the airfoil chord.

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## REFERENCE

1. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACR No. L5C05, 1945.

TABLE I

NACA $65_{(318)}$-419 $\left[\begin{array}{ll} a = 1.0 & c_{l_i} = 0.5 \\ a = 0.8 & c_{l_i} = -0.5 \\ a = 0.5 & c_{l_i} = 0.4 \end{array}\right]$

(Stations and ordinates given in percent of airfoil chord)

| Upper Surface | | | Lower Surface | |
|---|---|---|---|---|
| Station | Ordinate | | Station | Ordinate |
| 0 | 0 | | 0 | 0 |
| .222 | 1.501 | | .778 | -1.265 |
| .441 | 1.835 | | 1.059 | -1.503 |
| .903 | 2.351 | | 1.597 | -1.843 |
| 2.102 | 3.323 | | 2.898 | -2.431 |
| 4.551 | 4.810 | | 5.449 | -3.302 |
| 7.032 | 5.982 | | 7.968 | -3.966 |
| 9.532 | 6.971 | | 10.468 | -4.511 |
| 14.559 | 8.543 | | 15.441 | -5.375 |
| 19.613 | 9.750 | | 20.387 | -6.014 |
| 24.683 | 10.651 | | 25.317 | -6.499 |
| 29.765 | 11.303 | | 30.235 | -6.835 |
| 34.858 | 11.710 | | 35.142 | -7.048 |
| 39.958 | 11.883 | | 40.042 | -7.115 |
| 45.039 | 11.771 | | 44.961 | -7.019 |
| 50.220 | 11.346 | | 49.780 | -6.736 |
| 55.337 | 10.587 | | 54.663 | -6.305 |
| 60.371 | 9.601 | | 59.629 | -5.767 |
| 65.361 | 8.483 | | 64.639 | -5.173 |
| 70.319 | 7.314 | | 69.681 | -4.530 |
| 75.249 | 6.117 | | 74.751 | -3.837 |
| 80.131 | 4.909 | | 79.869 | -3.087 |
| 85.057 | 3.759 | | 84.943 | -2.239 |
| 90.054 | 2.691 | | 89.946 | -1.307 |
| 95.055 | 1.526 | | 94.945 | -0.470 |
| 100.000 | 0 | | 100.000 | 0 |

L.E. radius: 2.184
Slope of radius through L.E.: 0.201

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TABLE II

| LOCKHEED D-20B | | | |
|---|---|---|---|
| (Stations and ordinates given in percent of airfoil chord) | | | |
| Upper Surface | | Lower Surface | |
| Station | Ordinate | Station | Ordinate |
| 0 | 1.63 | 0 | 0 |
| .5 | 2.54 | .5 | -.86 |
| .75 | 2.89 | .75 | -1.11 |
| 1.25 | 3.48 | 1.25 | -1.46 |
| 2.50 | 4.71 | 2.50 | -1.99 |
| 5.00 | 6.58 | 5.00 | -2.67 |
| 7.50 | 8.00 | 7.50 | -3.23 |
| 10.00 | 9.18 | 10.00 | -3.69 |
| 15 | 10.94 | 15 | -4.42 |
| 20 | 12.17 | 20 | -4.99 |
| 25 | 13.06 | 25 | -5.41 |
| 30 | 13.64 | 30 | -5.69 |
| 35 | 13.97 | 35 | -5.88 |
| 40 | 14.02 | 40 | -5.98 |
| 45 | 13.76 | 45 | -5.98 |
| 50 | 13.20 | 50 | -5.83 |
| 55 | 12.40 | 55 | -5.50 |
| 60 | 11.37 | 60 | -5.02 |
| 65 | 10.10 | 65 | -4.44 |
| 70 | 8.69 | 70 | -3.82 |
| 75 | 7.24 | 75 | -3.19 |
| 80 | 5.79 | 80 | -2.54 |
| 85 | 4.35 | 85 | -1.91 |
| 90 | 2.90 | 90 | -1.28 |
| 95 | 1.45 | 95 | -.63 |
| 100 | 0 | 100 | 0 |
| L.E. radius is 0.0256c on a line $18^{\circ}$-40' from the chord. | | | |

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TABLE III

| NACA 2418 | | | |
|---|---|---|---|
| (Stations and ordinates given in percent of airfoil chord) | | | |
| Upper Surface | | Lower Surface | |
| Station | Ordinate | Station | Ordinate |
| 0 | ---- | 0 | 0 |
| 1.25 | 3.28 | 1.25 | -2.45 |
| 2.50 | 4.45 | 2.50 | -3.44 |
| 5.00 | 6.03 | 5.00 | -4.68 |
| 7.50 | 7.17 | 7.50 | -5.48 |
| 10 | 8.05 | 10 | -6.03 |
| 15 | 9.34 | 15 | -6.74 |
| 20 | 10.15 | 20 | -7.09 |
| 25 | 10.65 | 25 | -7.18 |
| 30 | 10.88 | 30 | -7.12 |
| 40 | 10.71 | 40 | -6.71 |
| 50 | 9.89 | 50 | -5.99 |
| 60 | 8.65 | 60 | -5.04 |
| 70 | 7.02 | 70 | -3.97 |
| 80 | 5.08 | 80 | -2.80 |
| 90 | 2.81 | 90 | -1.53 |
| 95 | 1.55 | 95 | -.87 |
| 100 | (.19) | 100 | (-.19) |
| 100 | ----- | 100 | 0 |
| L.E. radius: 3.56<br>Slope of radius through L.E.: 0,10 | | | |

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TABLE IV

| VEGA AIRFOIL (MODIFIED NACA 2419) | | | |
|---|---|---|---|
| (Stations and ordinates given in percent of airfoil chord) | | | |
| Upper Surface | | Lower Surface | |
| Station | Ordinate | Station | Ordinate |
| 0 | 0 | 0 | 0 |
| 0.50 | 2.018 | .50 | -1.380 |
| .75 | 2.385 | .75 | -1.724 |
| 1.25 | 2.968 | 1.25 | -2.237 |
| 2.50 | 4.029 | 2.50 | -3.117 |
| 5.00 | 5.498 | 5.00 | -4.204 |
| 7.50 | 6.587 | 7.50 | -4.932 |
| 10 | 7.472 | 10 | -5.476 |
| 15 | 8.870 | 15 | -6.262 |
| 20 | 9.929 | 20 | -6.836 |
| 25 | 10.706 | 25 | -7.210 |
| 30 | 11.212 | 30 | -7.415 |
| 35 | 11.472 | 35 | -7.498 |
| 40 | 11.507 | 40 | -7.490 |
| 45 | 11.340 | 45 | -7.359 |
| 50 | 10.987 | 50 | -7.088 |
| 55 | 10.457 | 55 | -6.673 |
| 60 | 9.757 | 60 | -6.135 |
| 65 | 8.894 | 65 | -5.501 |
| 70 | 7.884 | 70 | -4.787 |
| 75 | 6.759 | 75 | -4.006 |
| 80 | 5.515 | 80 | -3.190 |
| 85 | 4.190 | 85 | -2.355 |
| 90 | 2.808 | 90 | -1.523 |
| 95 | 1.408 | 95 | -0.714 |
| 100 | 0 | 100 | 0 |
| Leading edge radius: 3.055 | | | |

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TABLE V

| NACA $65_2$-515 (modified) a = 1.0 | | | |
|---|---|---|---|
| (Stations and ordinates given in percent of airfoil chord) | | | |
| Upper Surface | | Lower Surface | |
| Station | Ordinate | Station | Ordinate |
| 0 | 0 | 0 | 0 |
| .268 | 1.225 | .732 | -.975 |
| .491 | 1.506 | 1.009 | -1.156 |
| .958 | 1.945 | 1.542 | -1.409 |
| 2.165 | 2.765 | 2.835 | -1.835 |
| 4.622 | 4.013 | 5.378 | -2.433 |
| 7.106 | 4.999 | 7.894 | -2.879 |
| 9.603 | 5.830 | 10.397 | -3.246 |
| 14.621 | 7.173 | 15.379 | -3.809 |
| 19.657 | 8.204 | 20.343 | -4.224 |
| 24.705 | 8.996 | 25.295 | -4.520 |
| 29.759 | 9.578 | 30.241 | -4.718 |
| 34.818 | 9.968 | 35.182 | -4.819 |
| 39.879 | 10.175 | 40.121 | -4.819 |
| 44.941 | 10.165 | 45.059 | -4.689 |
| 50.000 | 9.926 | 50.000 | -4.410 |
| 55.054 | 9.458 | 54.946 | -3.982 |
| 60.099 | 8.811 | 59.901 | -3.435 |
| 65.135 | 8.039 | 64.865 | -2.889 |
| 70.160 | 7.173 | 69.840 | -2.313 |
| 75.174 | 6.222 | 74.826 | -1.746 |
| 80.176 | 5.185 | 79.824 | -1.205 |
| 85.165 | 4.076 | 84.835 | -0.712 |
| 90.139 | 2.886 | 89.861 | -.302 |
| 95.093 | 1.585 | 94.907 | -.005 |
| 100.000 | 0 | 100.000 | 0 |
| L.E. radius: 1.505<br>Slope of radius through L.E.: 0.211 | | | |

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TABLE VI

| LOCKHEED D-12A | | | |
|---|---|---|---|
| (Stations and ordinates given in percent of airfoil chord) | | | |
| Upper Surface | | Lower Surface | |
| Station | Ordinate | Station | Ordinate |
| 0 | 0 | 0 | 0 |
| .5 | 1.91 | .5 | --- |
| .75 | 2.19 | .75 | --- |
| 1.25 | 2.62 | 1.25 | .963 |
| 2.50 | 3.46 | 2.50 | 1.200 |
| 5.00 | 4.75 | 5.00 | 1.475 |
| 7.50 | 5.76 | 7.50 | 1.600 |
| 10.00 | 6.60 | 10.00 | 1.670 |
| 15 | 7.99 | 15 | 1.736 |
| 20 | 9.01 | 20 | 1.761 |
| 25 | 9.73 | 25 | 1.778 |
| 30 | 10.16 | 30 | 1.787 |
| 35 | 10.32 | 35 | 1.792 |
| 40 | 10.20 | 40 | 1.797 |
| 45 | 9.73 | 45 | 1.799 |
| 50 | 9.10 | 50 | 1.799 |
| 55 | 8.36 | 55 | 1.782 |
| 60 | 7.53 | 60 | 1.733 |
| 65 | 6.63 | 65 | 1.610 |
| 70 | 5.70 | 70 | 1.383 |
| 75 | 4.75 | 75 | 1.150 |
| 80 | 3.80 | 80 | .925 |
| 85 | 2.85 | 85 | .695 |
| 90 | 1.90 | 90 | .460 |
| 95 | .95 | 95 | .230 |
| 100 | 0 | 100 | 0 |
| L.E. radius is 0.015c on a line 22° from the chord. | | | |

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# TABLE VII

| SUMMARY OF THE MORE IMPORTANT AERODYNAMIC CHARACTERISTICS OF THE VARIOUS AIRFOIL SECTIONS | | | | | | |
|---|---|---|---|---|---|---|
| Airfoil | Reynolds number | $\frac{dc_l}{d\alpha_o}$ | $c_{l_{max}}$ | $c_{d_{min}}$ | range of lift for low-drag | $c_{m_{a.c.}}$ |
| NACA $65_2$-515 (mod) a = 1.0 | $8.7 \times 10^6$ | 0.108 | 1.655 | 0.0043 | 0.250 to 0.740 | -0.086 |
| Lockheed D-12A | $9.0 \times 10^6$ | 0.109 | 1.555 | 0.0047 | 0.500 to 0.840 | -0.059 |
| NACA $65_{(318)}$-419 [a=1.0 $c_{l_i}$= 0.5<br>a=0.8 $c_{l_i}$=-0.5<br>a=0.5 $c_{l_i}$= 0.4] | $9.0 \times 10^6$ | 0.112 | 1.460 | 0.0046 | 0.160 to 0.650 | -0.047 |
| Lockheed D-20B | $8.9 \times 10^6$ | 0.103 | 1.330 | 0.0048 | -------------- | -0.060 |
| NACA 2418 | $8.9 \times 10^6$ | 0.103 | 1.475 | 0.0068 | -------------- | -0.044 |
| Vega (mod) 2419 | $8.9 \times 10^6$ | 0.098 | 1.440 | 0.0053 | -------------- | -0.051 |

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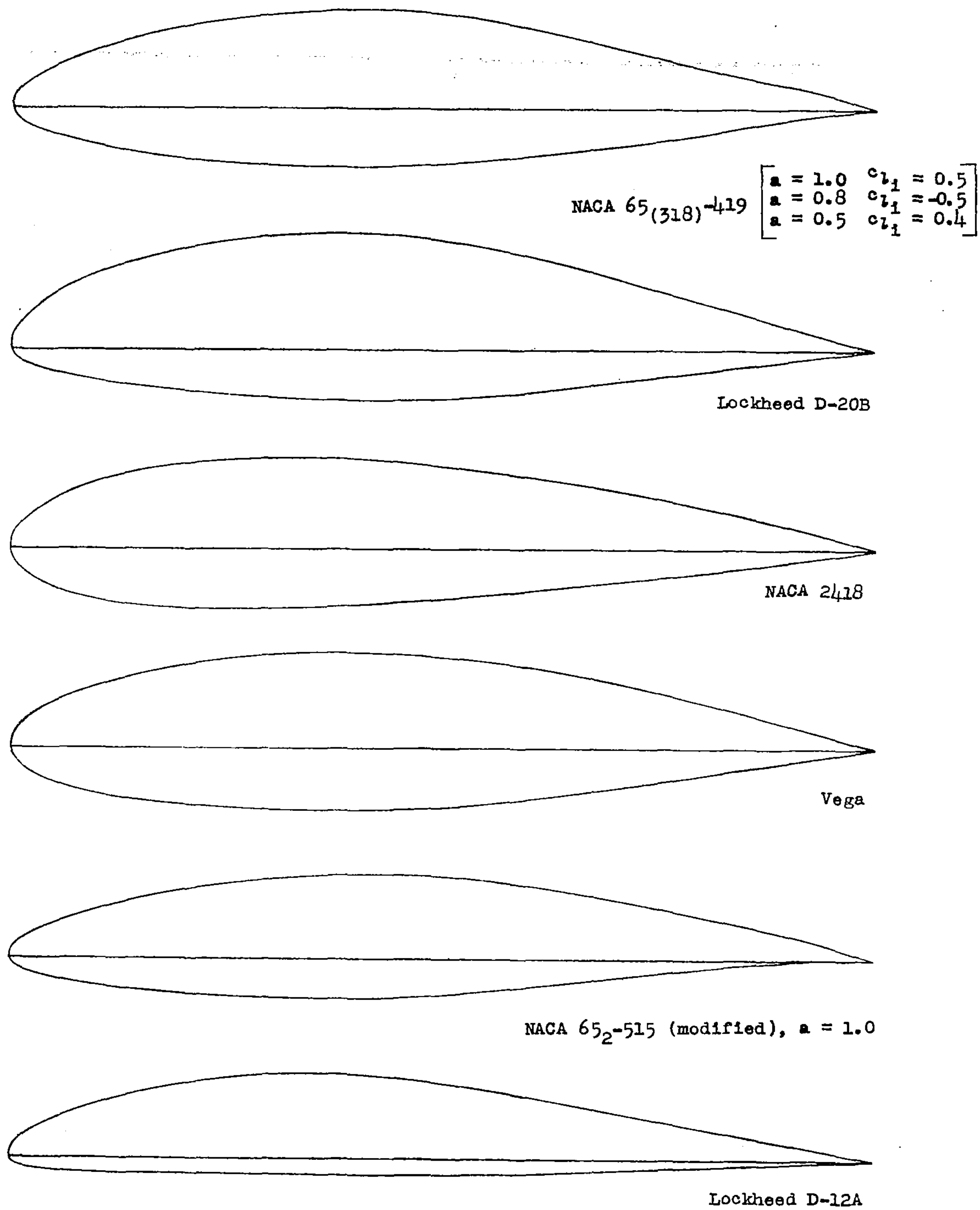


Figure 1.- A sketch of the various airfoil sections for the wing of the Vega XP2V-1 airplane.

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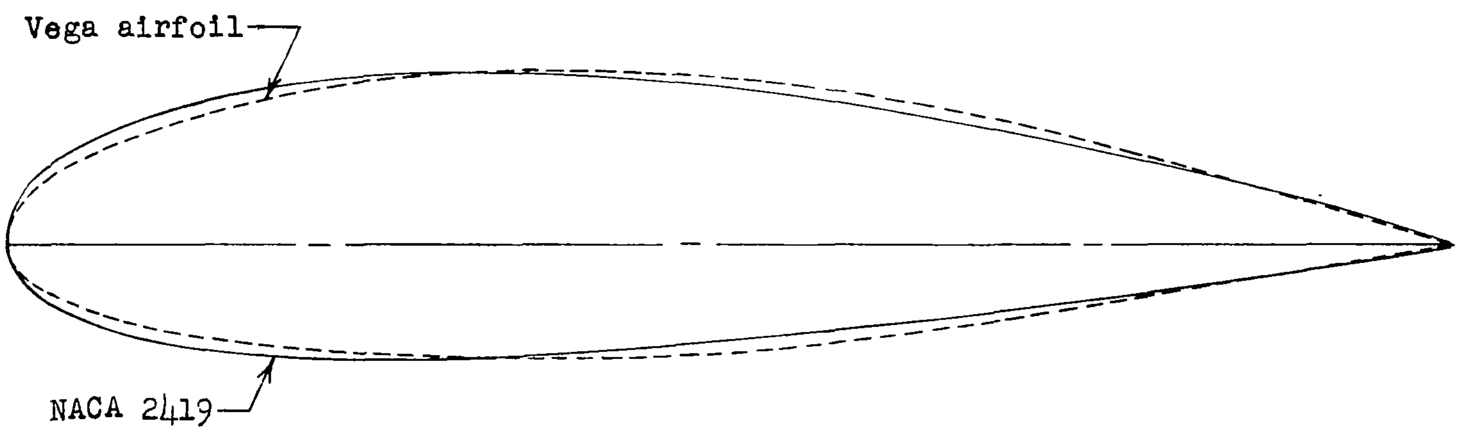


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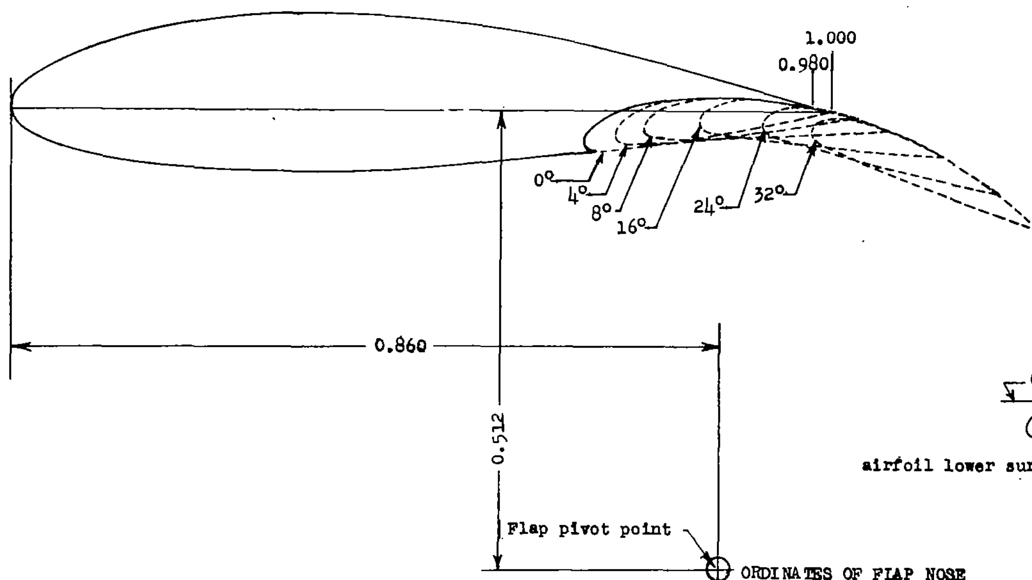
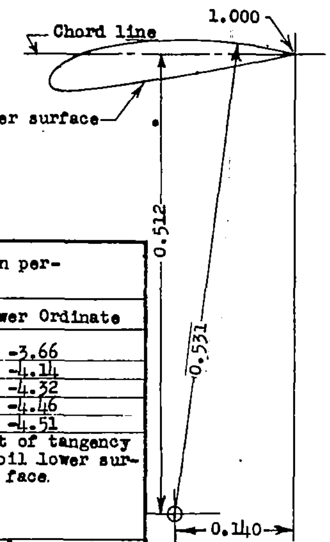
Figure 2.- A comparison of the airfoil profiles of the Vega and the NACA 2419 airfoil sections.




ORDINATES OF FLAP NOSE

(Stations and ordinates given in percent of airfoil chord)

| Station | Upper Ordinate | Lower Ordinate |
|---|---|---|
| 70.00 | -3.66 | -3.66 |
| 70.25 | -2.70 | -4.14 |
| 70.50 | -2.33 | -4.32 |
| 70.75 | -2.07 | -4.46 |
| 71.00 | -1.82 | -4.51 |
| 71.55 | ---- | Point of tangency airfoil lower surface. |
| | | |
| 72.50 | -0.79 | |
| 75.00 | 0.38 | |
| 77.50 | 1.15 | |
| 80.00 | Point of tangency 53.1-percent chord radius. | |

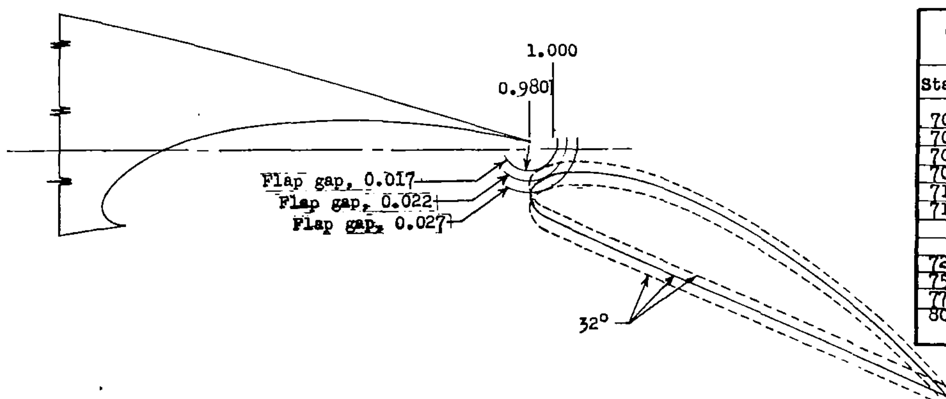



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Figure 3.- A sketch showing the general model arrangement, the flap profile, the flap ordinates and the gap dimensions for the Vega airfoil-flap model.

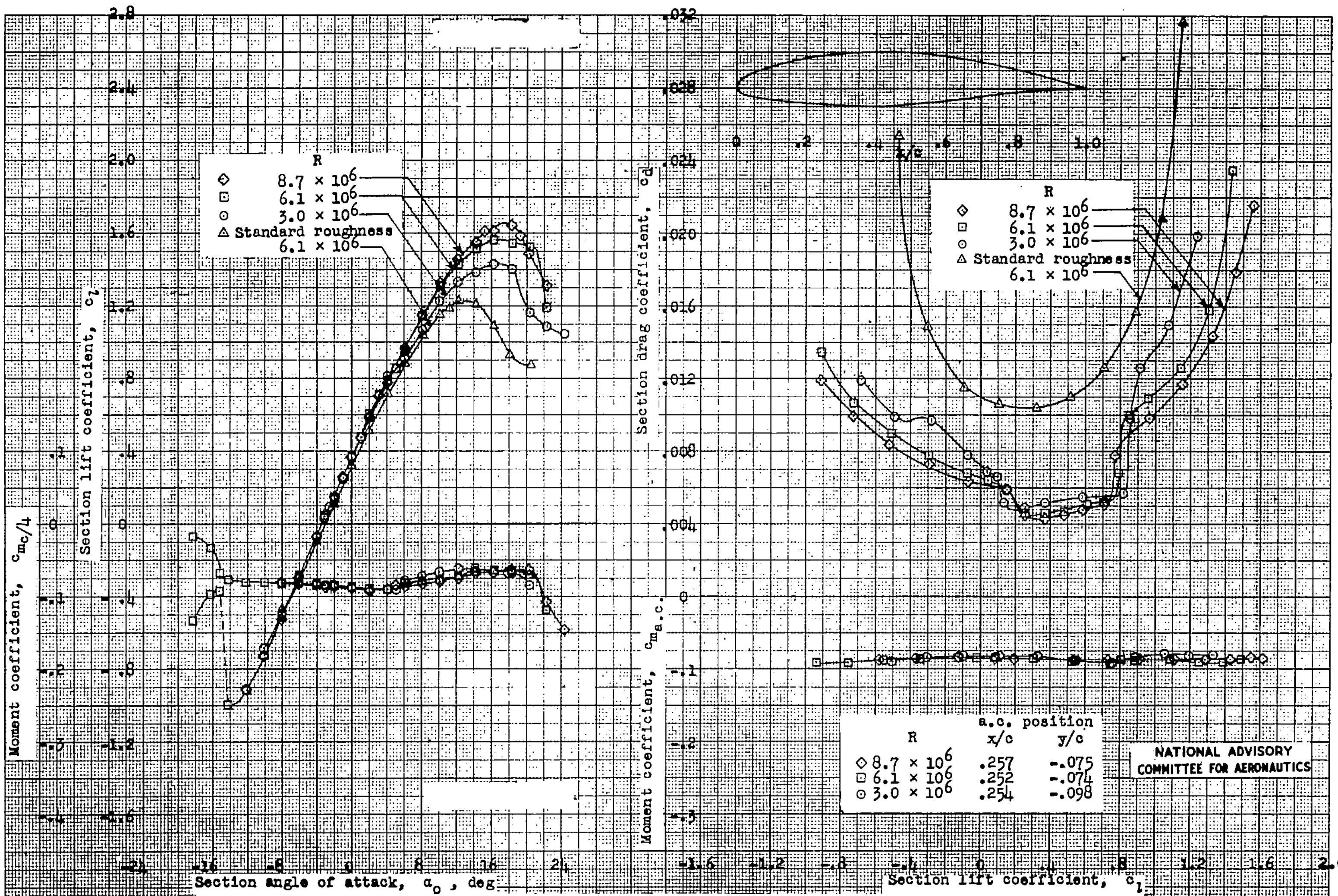


Figure 4.- Section aerodynamic characteristics for the NACA $65_2$-515 (modified) a = 1.0 airfoil; proposed tip section for the wing of the Vega XP2V-1 airplane. Test, TDT 336, 349.

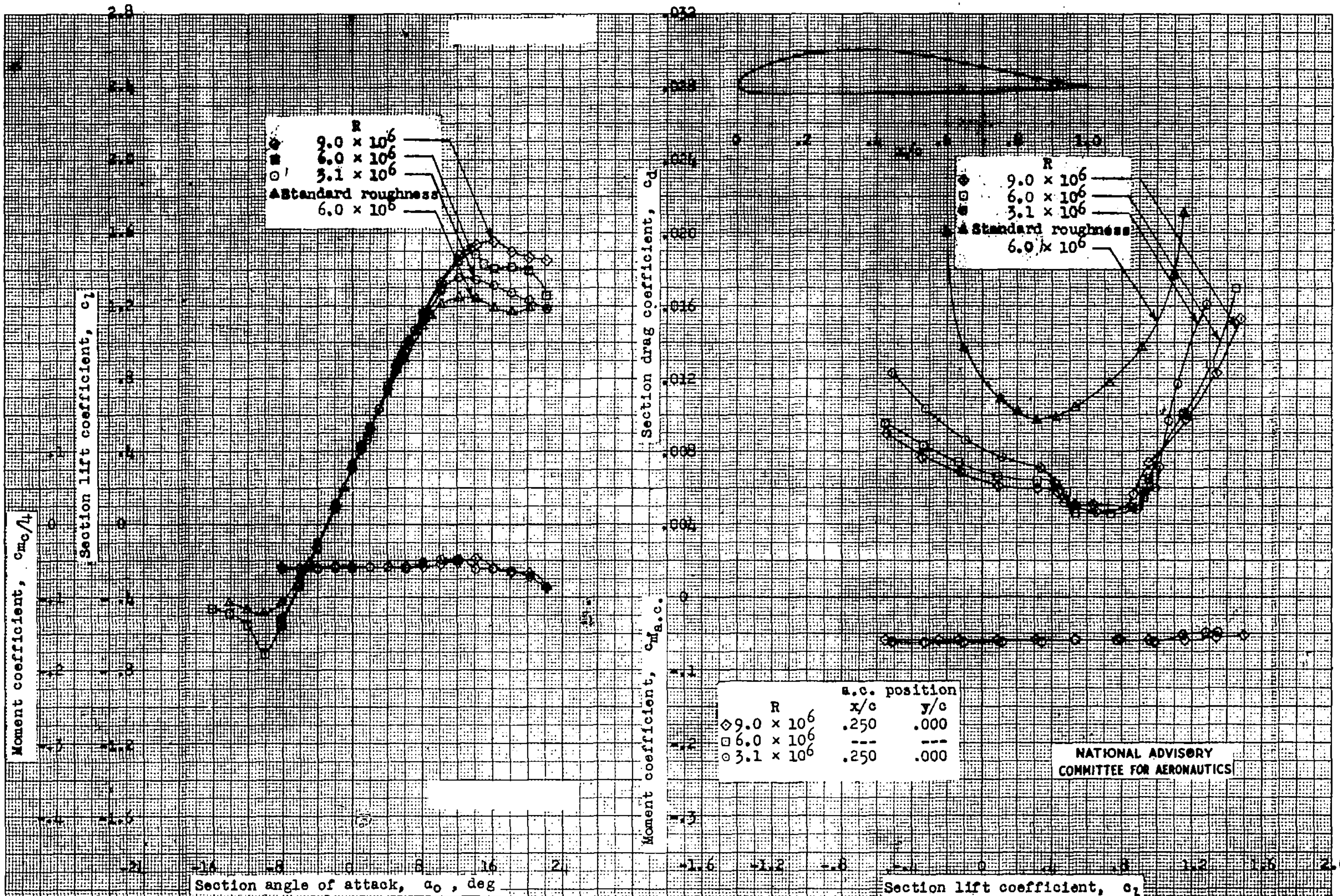


Figure 5.- Section aerodynamic characteristics for the Lockheed D-12A airfoil; proposed tip section for the wing of the Vega XP2V-1 airplane. Test, TDT 501, 503, 505.

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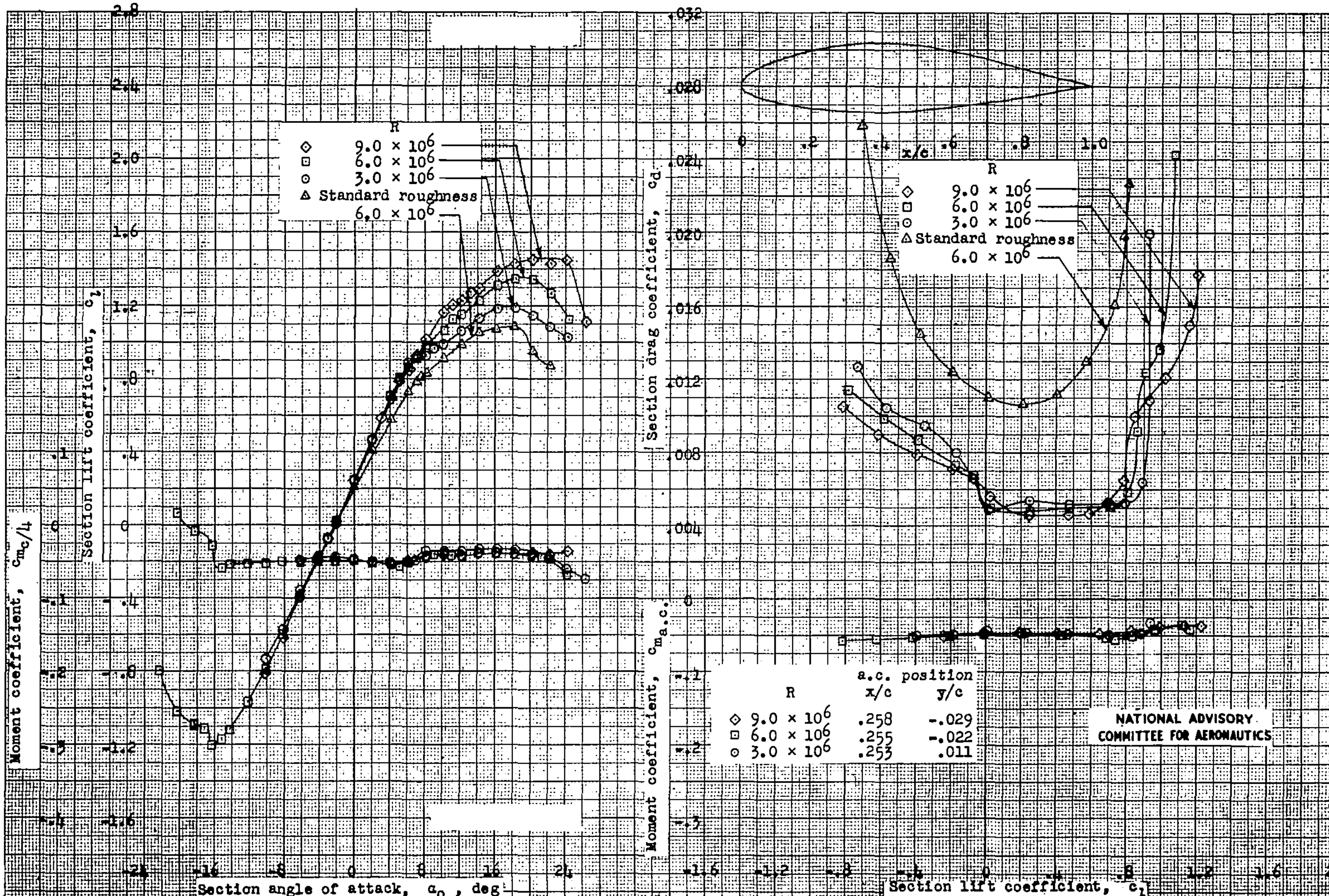


| R | a.c. position x/c | a.c. position y/c |
|---|---|---|
| ◇ 9.0 × $10^6$ | .258 | -.029 |
| □ 6.0 × $10^6$ | .255 | -.022 |
| ○ 3.0 × $10^6$ | .253 | .011 |

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Figure 6.- Section aerodynamic characteristics for the NACA $65_{(318)}$-419 $\left[\begin{array}{ll} a = 1.0, & c_{l_i} = 0.5 \\ a = 0.8, & c_{l_i} = -0.5 \\ a = 0.5, & c_{l_i} = 0.4 \end{array}\right]$ airfoil; proposed root section for the wing of the Vega XP2V-1 airplane. Tests, TDT 335, 342.

MR No. L5I21

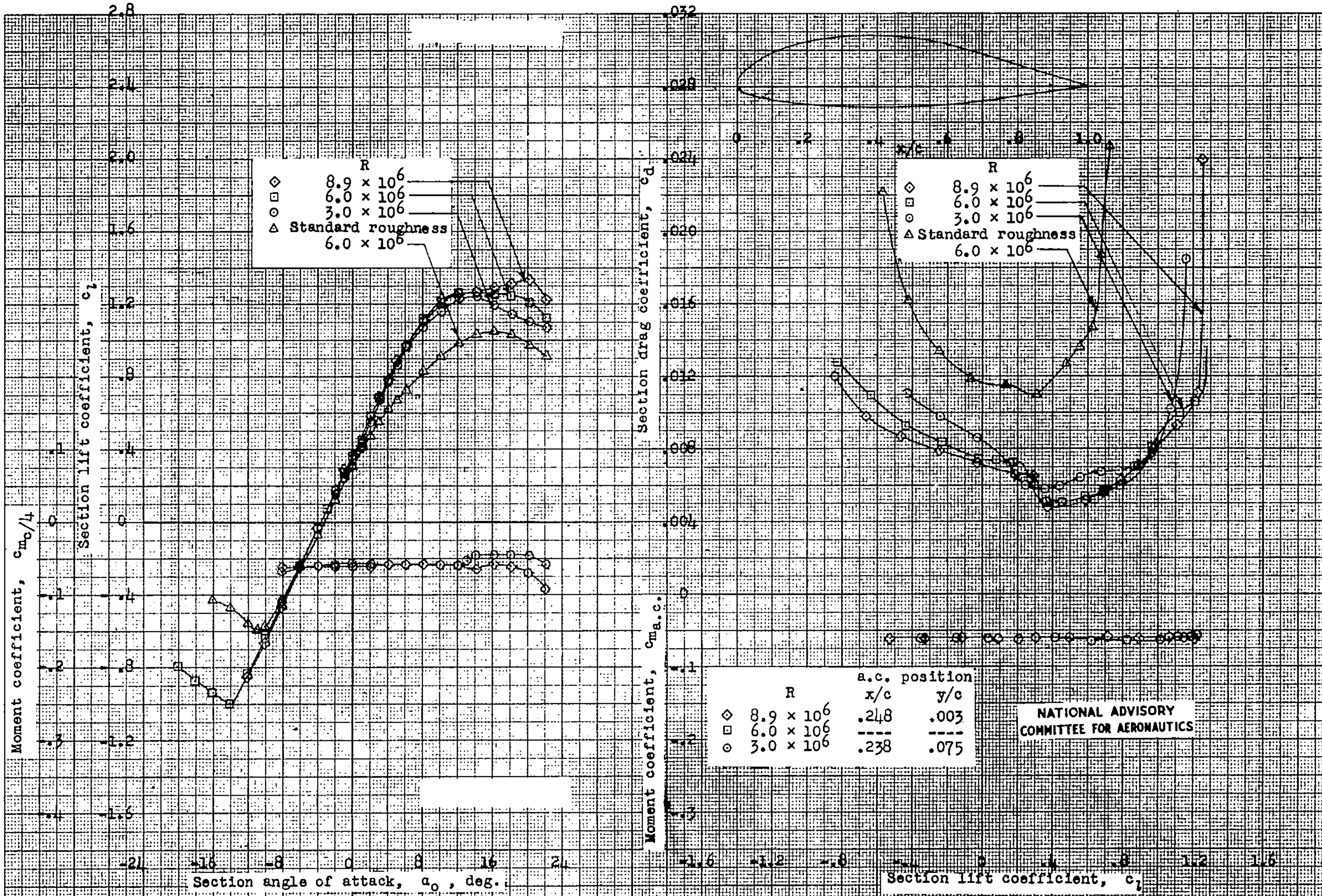


Figure 7.- Section aerodynamic characteristics for the Lockheed D-20B airfoil; proposed root section for the wing of the Vega XP2V-1 airplane. Tests, TDT 500, 502, 504.

MR No. L5I21

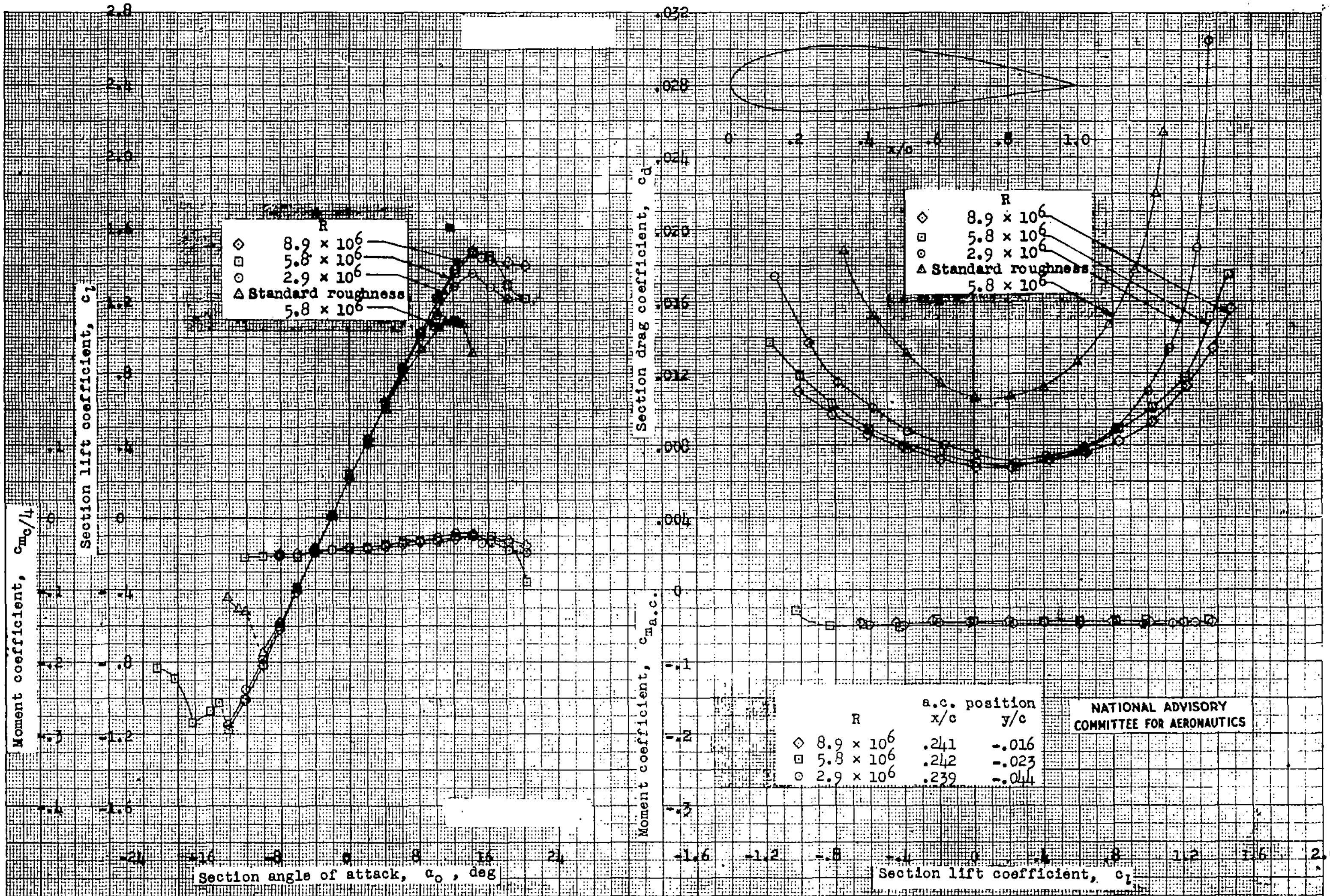


Figure 8.- Section aerodynamic characteristics for the NACA 2418 airfoil; proposed root section for the wing of the Vega XP2V-1 airplane. Test, TDT 465, 472, 774.

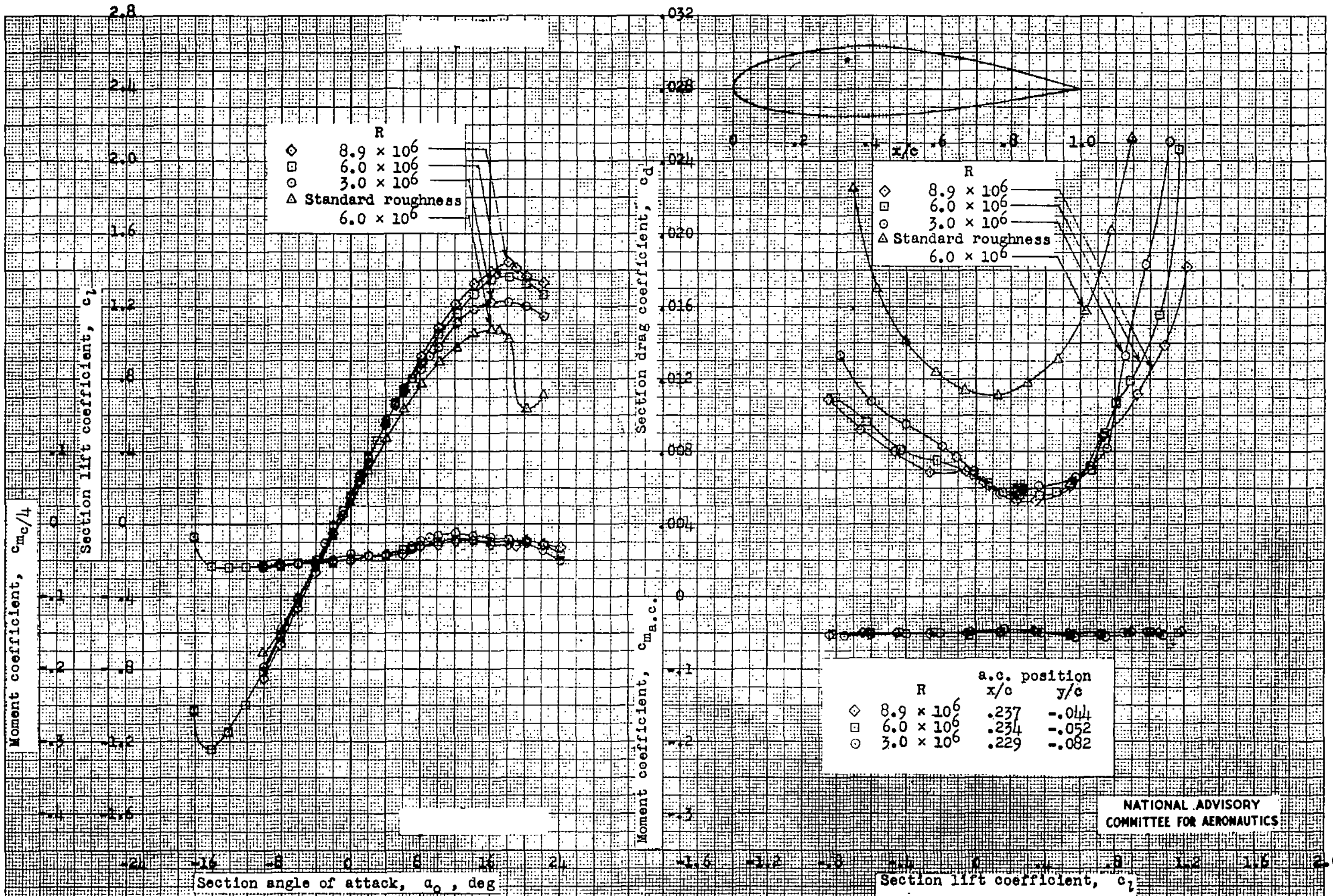


Figure 9.- Section aerodynamic characteristics for the Vega airfoil; proposed root section for the wing of the Vega XP2V-1 airplane. Tests, TDT 438, 441, 445.

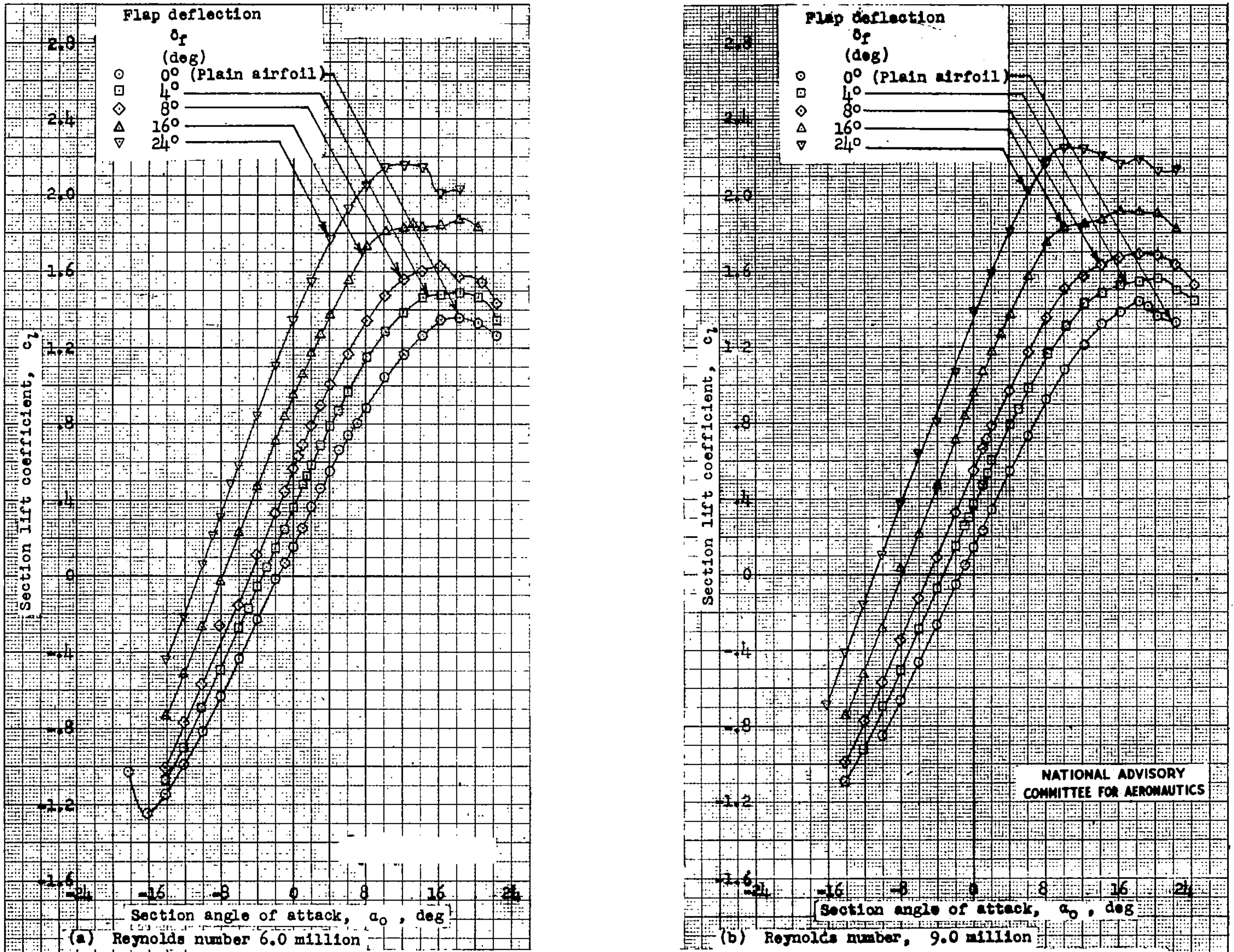


Figure 10.- Section lift coefficients for a Vega airfoil equipped with an 0.30c Fowler type flap; proposed root section for the wing of the Vega XP2V-1 airplane. Flap gap sealed; Tests, TDT 595.

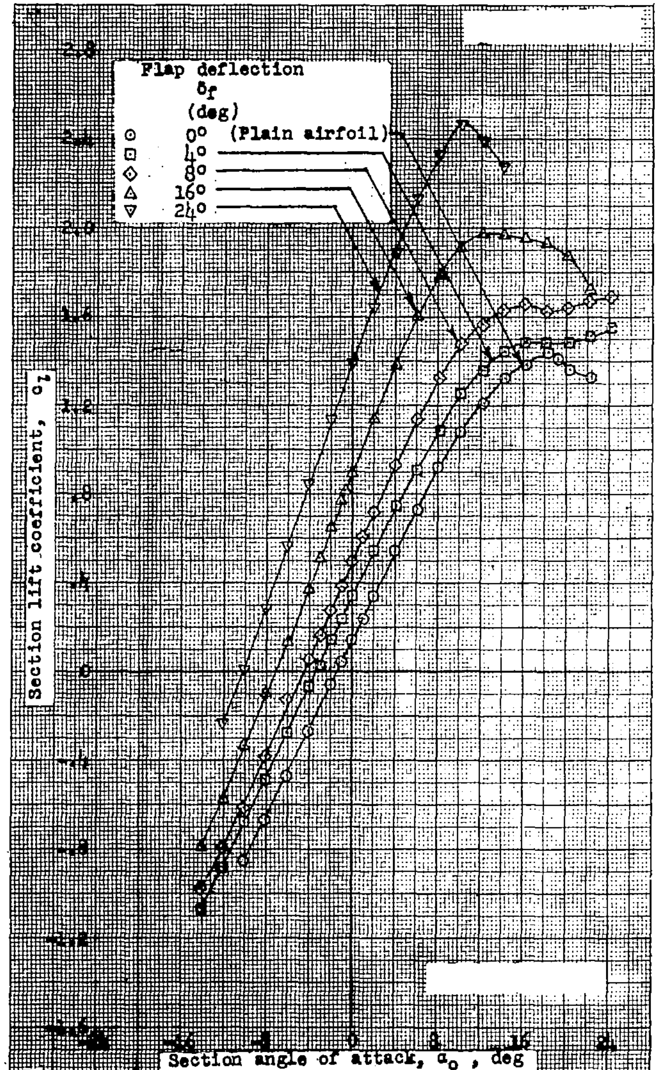


Figure 11.- Section lift coefficients for a Vega airfoil equipped with an 0.30c Fowler type flap; proposed root section for the wing of the Vega XP2V-1 airplane. Flap gap open; Reynolds, 9.0 million; Tests, TDT 597.

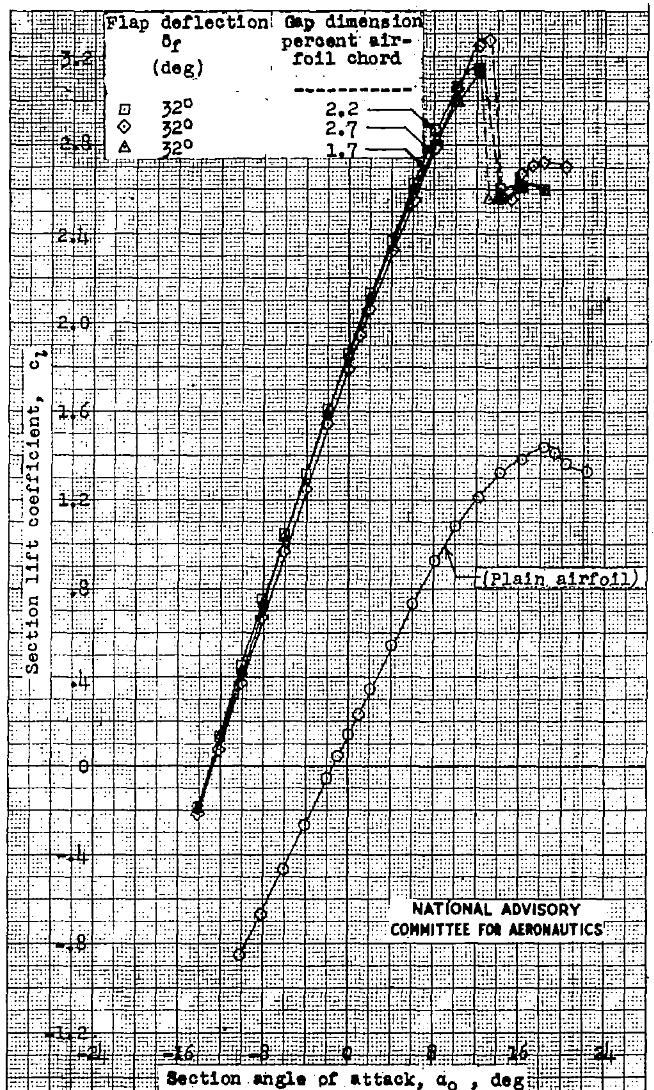


Figure 12.- Variation of section maximum lift coefficient with flap gap dimension. Vega airfoil flap model; Reynolds number, 9.0 million; Test, TDT 597.

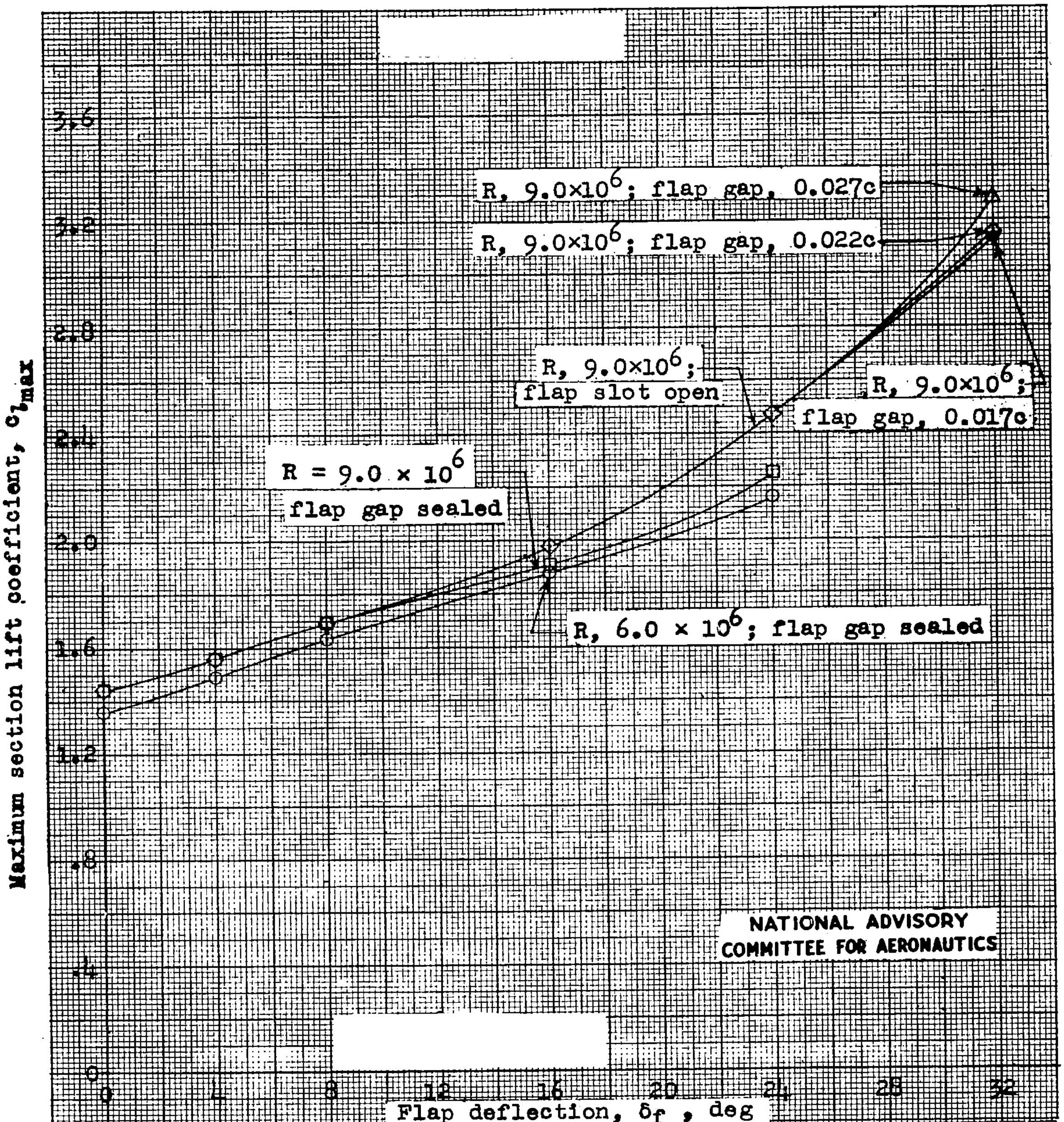


Figure 13.- Variation of the section maximum lift coefficient with flap deflection for various model configurations and Reynolds numbers. Vega airfoil-flap model.